TT 34: Superconductivity: Tunneling and Josephson Junctions

Time: Tuesday 9:30–13:00 Location: H 2053

Invited Talk TT 34.1 Tue 9:30 H 2053

Non-Equilibrium Spin- and Charge Transport Phenomena in Superconductor-Ferromagnet Hybrid Structures — •Torsten Pietsch — Department of Physics, University of Konstanz, Germany

Over the past few years, hybrid superconducting nanostructures attracted tremendous interest in condensed matter physics due to their great potential in dissipation-less spintronic devices with unprecedented switching rates. The practical realization of such devices, however, requires a complete understanding of the transfer and the dynamics of spin- and charge currents between superconducting (S) and ferromagnetic (F) circuit elements, as well as the coupling between spin- and charge degrees of freedom in these systems. Here we explore both local and non-local transport properties of lateral, superconducting spin-valves and ferromagnetic Josephson junctions. In diffusive S-FS'-S proximity junctions, the spin-polarized spacer leads to a non-sinusoidal current-phase relationship, which is investigated via the occurrence of Shapiro steps in the IV characteristics under microwave irradiation depending on the magnetization state of the F spacer. An interesting question remains, whether superconducting triplet pair correlations can be induced in extended S-F-S junctions incorporating a long ferromagnetic spacer with a dynamic magnetization via magnon scattering. The latter would provide means to generate spin-polarized supercurrents in S/F heterojunctions for superconducting spintronic applications.

TT 34.2 Tue 10:00 H 2053

Influence of Microwaves on Magnetic Switching in Nb-Al/AlO$_x$-(Nb)-PdFe-Nb Josephson Junctions — •Roberta Caruso[1,2], Davide Massarotti[1,2], Aymen Ben Hamida[3], Vitaly Bol'ginov[4], Alessandro Miano[1], Igor Vernik[5], Valery Ryazanov[4,6], Oleg Mukhanov[5], Francesco Tafuri[1,2], and Giovanni Piero Pepe[1,2] — [1]Dipartimento di Fisica, Università degli Studi di Napoli Federico II, I-80125 Napoli, Italy — [2]CNR-SPIN Institute - Superconductors, Innovative Materials and Devices, UOS Napoli, I-80100 Napoli, Italy — [3]National University of Science and Technology MISiS, Moscow, Russia — [4]Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka 142432, Russia — [5]Hypres, Inc., 175 Clearbrook Road, Elmsford, New York 10523, USA — [6]Faculty of Physics, National Research University Higher School of Economics, Moscow, Russia

Superconducting circuits have found application in various fields, due to their high speed and high energy efficiency. However, the practical, large scale application of these circuits is limited by the lack of compatible energy-efficient, high-speed and high capacity random access memories. In 2012 Nb-Al/AlO$_x$-(Nb)-PdFe-Nb have been proved to be random access magnetic memories compatible with RSFQ logic. However, the performances of such devices can be limited by the external addressing circuitry. Here we discuss the effect on magnetic switching of RF fields, in particular the enhancement of the separation between the 0 level and the 1 level when an external microwave field is applied, and its consequences on the performances of these devices.

TT 34.3 Tue 10:15 H 2053

Fluxoid-periodicity crossover from $\frac{h}{2e}$ to $\frac{h}{e}$ in Al nano-loops — •Rebekka Garreis[1], Julian Braun[1], Christopher Espy[1], Omri Sharon[2], Florian Strigl[1], Yosef Yeshurun[2], and Elke Scheer[1] — [1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [2]Department of Physics and Institute of Nano Technology and Advanced Materials, Bar-Ilan University, 5290002 Ramat-Gan, Israel

In a multiply connected superconductor, the fluxoid is quantized in units of $\Phi_0 = \frac{h}{2e}$, where the 2e is a hallmark of electron pairing in the superconductor. Theoretical studies [1] have predicted that in superconducting nano-loops with length-scale $a < \xi_0$ the dominant periodicity of the flux is $2\Phi_0$ rather than Φ_0. Aluminum is a natural choice of material for experimental verification of this prediction because of its relatively large bulk coherence length ($\xi_0 = 1.6\,\mu$m). First measurements on aluminum networks with loop sizes of roughly 320 nm and 420 nm at temperatures between 300 and 1400 mK reveal usual Little-Parks flux periodicity of Φ_0 at low temperatures and indicate a crossover to $2\Phi_0$ periodicity at temperatures above 1300 mK. So far, the relatively low critical field of aluminum, in particular close to the transition temperature, and the large period of small loops, allowed the measurement of one Φ_0 period only. To be able to achieve a full experimental verification, measurements on networks with a loop size of 500 nm at temperatures between 1100 and 1550 mK are performed.

TT 34.4 Tue 10:30 H 2053

Renormalization of Charging Energy in superconducting Single Electron Transistors — •Susanne Sprenger, Thomas Lorenz, and Elke Scheer — Universität Konstanz

A small island connected by two tunnel junctions and a gate electrode forms a single electron transistor (SET) that shows Coulomb blockade (CB) effects. In the case of weak-coupling, Orthodox Theory (OT) can be used to quantitatively describe the behavior of these devices even when considering superconducting transport [1,2].

Transport in the strong-coupling regime, however, is not yet fully understood and difficult to address with traditional SETs. We present a measurement scheme where all coupling regimes can be addressed. The sample is composed of an AlO_x tunnel barrier and a mechanically controllable break junction, that can be tuned throughout all coupling regimes. When tuning the sample from the orthodox regime to higher couplings the transport properties are changing, which is most prominent in the superconducting state. We observe a renormalization of the charging energy for intermediate couplings as well as the disappearance of the CB for very high couplings, similar to the findings of [3].

[1] R. J. Fitzgerald, Phys. Rev. B 57, R11073(R) (1997)
[2] K. K. Likharev, Proc. IEEE 87, 606 (1999)
[3] S. Jezouin, Nature 536, 58-62 (2016)

TT 34.5 Tue 10:45 H 2053

Evidence of Shapiro steps in hysteretic nanobridge weak link Josephson junctions — •Connor Shelly, Patrick See, Jane Ireland, and Jonathan Williams — National Physical Laboratory, Hampton Rd, Teddington, TW11 0LW, United Kingdom

We present experimental work demonstrating the response of superconducting nanobridge Josephson junctions to microwave irradiation. Our nanobridge devices exhibit hysteretic current-voltage characteristics (IVC) below 7 K. In this regime the devices enter a resistive state when the applied current is increased to a value greater than the junction critical current I_c. When the applied current is then reduced, the nanobridge remains in the resistive state until the re-trapping current I_r is reached, where $I_r < I_c$. Unlike traditional tunnel junctions it is widely considered that the origin of this hysteresis is thermal with the device remaining in a non-superconducting state such that$T > T_c$ on the re-trapping branch of the IVC [1-3]. However we present evidence of Shapiro steps in the hysteretic branch of the IVC.

[1] W. J. Skocpol, M. R. Beasley, M. Tinkham, J. Appl. Phys. 45, 4054, (1974)
[2] D. Hazra, L. M. A. Pascal, H. Courtois, A. K. Gupta, Phys. Rev. B 82, 184530 (2010).
[3] A. Blois, S. Rozhko, L. Hao, J. C. Gallop, E. J. Romans, Supercond. Sci. Technol. 30, 014003 (2017).

TT 34.6 Tue 11:00 H 2053

Tunneling spectroscopy of superconducting $In_xSn_{1-x}Te$ nano-plates — •Fan Yang, Mengmeng Bai, Zhiwei Wang, and Yoichi Ando — Institute of Physics II, University of Cologne, Zuelpicher Str. 77, 50937 Cologne, Germany

With indium doping, superconductivity can be induced in SnTe, a well-known topological crystalline insulator. Due to the possible co-existence of superconductivity and non-trivial band topology, $In_xSn_{1-x}Te$ provides a promising platform for searching for topological superconductivity.

In this talk, we present our study on the point-contact spectroscopy of superconducting $In_xSn_{1-x}Te$ nanostructures. $In_xSn_{1-x}Te$ nano-plates were grown on Si/SiO_2 substrates via vapor-transport method. After the growth, Au contacts with naturally formed tunnel barrier were fabricated on selected nano-plates. The conductance spectra of Au contacts were measured in a dilution refrigerator, and non-trivial sub-gap features were observed in several Au contacts at the tunnel limit. The preliminary results are presented and discussed.

15 min. break.

TT 34.7 Tue 11:30 H 2053

Transport properties of an electron-hole bilayer/superconductor hybrid junction — •D. Bercioux[1,2], T.M. Klapwijk[3], and F.S. Bergeret[1,4] — [1]Donostia International Physics Center (DIPC), Manuel de Lardizbal 4, E-20018 San Sebastián, Spain — [2]IKERBASQUE, Basque Foundation of Science, 48011 Bilbao, Spain — [3]Kavli Institute of Nanoscience Delft University of Technology — [4]Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU, 20018 Donostia-San Sebastián, Spain

We investigate the transport properties of an electron-hole bilayer (EBL) contacted with normal and superconducting leads. We assume that the EBL hosts an exciton condensate (EC) described by a BCS-like model with a gap in the quasiparticle density of states. Contrary to the existing proposal based on Coulomb drag measurements [1,2], we show that the existence of the EC via transport measurements in the sub-gap regime. Here, transport properties are determined by the competition of the standard Andreev reflection at the interface between the superconductor/EC with crossed reflection at the semi-metal/EC. The latter converts electrons from one layer to the other [2]. We show that the existence of a finite gap manifests in a minimum of the conductance at low voltage bias [3].

[1] Croxall et al., Phys. Rev. Lett. 101, 246801 (2008).
[2] Rontani & Sham, Phys. Rev. Lett. 94, 186404 (2005).
[3] DB, Klapwijk, & Bergeret Phys. Rev. Lett. 119, 067001 (2017).

TT 34.8 Tue 11:45 H 2053

Spin-flip enhanced thermoelectricity in superconductor-ferromagnet bilayers — •Ali Rezaei, Akash Kamra, Peter Machon, and Wolfgang Belzig — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

We study the effects of Zeeman-splitting and spin-flip scattering in a superconductor (S) on the thermoelectric properties of a tunneling contact to a metallic ferromagnet (F) using the Green's function method. A giant thermopower has been theoretically predicted and experimentally observed in such structures. This huge thermoelectric effect is attributed to the spin-dependent particle-hole asymmetry in the tunneling density of states in the S/F heterostructure. Here, we evaluate the S density of states and thermopower for a range of temperatures, Zeeman-splitting, and spin-flip scattering. In contrast to the naive expectation, we find that the spin-flip scattering strongly enhances the thermoelectric performance of the system in the low-field and low-temperature regime. This is attributed to a complex interplay between the charge and spin conductances caused by the softening of the spin-dependent superconducting gaps. The maximal value of the thermopower exceeds k_B/e by a factor of ~ 5 and has a nonmonotonic dependence on Zeeman-splitting and spin-flip rate. We also demonstrate that the incoherent broadening leads to a drastic reduction of the thermoelectric performance.

[1] A. Rezaei, A. Kamra, P. Machon, W. Belzig, arXiv:1711.11538v1

TT 34.9 Tue 12:00 H 2053

Yu-Shiba-Rusinov states in magnetic Josephson junctions — •Andreas Costa, Denis Kochan, and Jaroslav Fabian — University of Regensburg, 93040 Regensburg, Germany

Superconductivity and ferromagnetism are two nominally antagonistic states of matter, which lead to extraordinary physical phenomena when combined in one system. Perhaps most striking is the emergence of 0-π transitions in magnetic Josephson junctions. We study the bound state spectrum in S/I/S Josephson junctions in which the interlayer (I) hosts point-like scalar and magnetic impurities. In addition to Andreev-like subgap states, stemming from the coherent coupling of the superconductors (S), magnetic impurities give rise to superimposed Yu-Shiba-Rusinov (YSR)-like states. We show that these states have genuine features, which can be tuned by changing the junction characteristics and allow to clearly identify the states in STM experiments. Particularly interesting are zero-energy YSR-like states in the center of the superconducting gap, which form for a wide range of accessible junction configurations. By calculating the Josephson current flow across the system from the spectrum, we unravel a unique connection between these zero-energy YSR-like states and the appearance of 0-π transitions in the current flow. Our findings shed new light on the physics of 0-π transitions in Josephson junctions.

This work was supported by DFG SFB Nos. 689 and 1277, by the European Union's Horizon 2020 research and innovation programme under Grant agreement No. 696656, and by the International Doctorate Program Topological Insulators of the Elite Network of Bavaria.

TT 34.10 Tue 12:15 H 2053

Charge Transfer across a Scanning Tunneling Microscope Junction in Presence of a Macroscopic Impedance — •Simon Dambach[1], Christian R. Ast[2], Björn Kubala[1], Jacob Senkpiel[2], Markus Etzkorn[2], and Joachim Ankerhold[1] — [1]Institute for Complex Quantum Systems, Ulm University, Ulm, Germany — [2]MPI for Solid State Research, Stuttgart, Germany

When it comes to probing electronic structure on an atomic scale, scanning tunneling microscopy has evolved into one of the most powerful and versatile experimental techniques over the last decades. Recent progress in pushing the energy resolution to the low energy scales that are necessary for resolving extremely sharp spectral features (e.g., superconducting gaps, Yu-Shiba-Rusinov states, or Kondo peaks) has led to the development of an ultra-precise scanning tunneling microscope operating at 15 mK [1]. At these low temperatures, the device is operated at the quantum limit, i.e., the granularity of the current becomes non-negligible. The ultimate resolution is limited here by the electromagnetic interaction of the tunneling charge quantum with the surrounding and the capacitative noise of the junction.

In this talk, we provide a theoretical study of the electrical current across a scanning tunneling microscope junction in presence of an environmental macroscopic impedance. On the basis of $P(E)$ theory, which describes the probability for a loss or gain in energy during a tunneling process, we obtain corrections to the $I(V)$ characteristics which reproduce data of current measurements with high accuracy.

[1] C. R. Ast et al., Nat. Commun. **7**, 13009 (2016)

TT 34.11 Tue 12:30 H 2053

Single Channel Josephson Effect in a High Transmission Tunnel Junction — •Christian R. Ast[1], Jacob Senkpiel[1], Simon Dambach[2], Björn Kubala[2], Ciprian Padurariu[2], Berthold Jäck[1], Markus Etzkorn[1], Juan Carlos Cuevas[3], Joachim Ankerhold[2], and Klaus Kern[1] — [1]MPI für Festkörperforschung, Stuttgart — [2]Institut für Komplexe Quantensysteme, Universität Ulm — [3]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Spain

Andreev bound states lie at the heart of many phenomena involving scattering with superconductors, such as Yu-Shiba-Rusinov states, Majorana bound states, or the Josephson effect. In most cases it is sufficient to approximate the Josephson effect by an ensemble of many, nearly opaque transport channels. However, in scanning tunneling microscopy (STM), where only very few transport channels are realized and arbitrary transmissions can be achieved, this approximation may break down and the full energy-phase relation of the Andreev bound states has to be considered. Using the manipulation techniques available to STM, we exploit a single atom contact at high transmission to demonstrate the consequences of single channel transport for the Josephson effect. We demonstrate single channel transport through the analysis of multiple Andreev reflections at various transmission setpoints and discuss the transition from the tunneling approximation to the full Andreev bound state description in the dynamical Coulomb blockade regime.

TT 34.12 Tue 12:45 H 2053

Phase-dependent heat transport in multi-terminal Josephson junctions — •Sun-Yong Hwang and Björn Sothmann — Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany

Phase-coherent heat transport has received a lot of attention recently as it offers the possibility to control heat flows at the nanoscale with the same precision as charge currents [1]. Thus, phase-coherent caloritronics provides not only fundamental insights into heat transport at the nanoscale but can also lay the foundations for future thermal logic and energy management in small electric circuits.

Here, we investigate the phase-dependent linear thermal conductance in multi-terminal Josephson junctions. The thermal conductance in our system can be controlled via the magnetic flux through the junction and the phase bias configuration among the superconductors. Remarkably, the phase- and flux-controlled heat can show a strongly unidirectional transport property which can be utilized for a heat circulator or a highly efficient cooler.

[1] A. Fornieri, F. Giazotto, Nat. Nanotechn. 12, 944 (2017).